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Patentanmeldung Nr. Patent application No. Demande de brevet n°

04003144.5

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

A refrigerator with a variable speed compressor and a method for controlling variable cooling capacity thereof

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The present invention relates to a refrigerator comprising a compressor having a variable cooling capacity and control means for controlling such compressor in response to the temperature inside the refrigerator, as well as to a method for automatically speeding up the cooling time of the food stored in a refrigerator without user interaction and with limited energy consumption. With the term "refrigerator" as used in the description and in the appended claims we mean any kind of domestic refrigerator and freezer. With the term compressor having variable cooling capacity we mean all kind of compressors having the possibility of changing the output, either by changing displacement of the compressor (for instance with the so called free piston compressor) or by changing the speed of the compressor (in case of fixed displacement) either continuously or stepwise. In general, modern freezers and refrigerators have a fast freezing or fast cooling feature. This feature must be activated by the user and consists in keeping the compressor running at its maximum cooling capacity for an appropriate fixed time (i.e. 24 hours). Such a known technique guarantees the maximum cooling speed and is suitable for the fast cooling of large amounts of food. When the amount of food is not very large, it leads to unnecessary food over-cooling and energy waste. On the other hand, the user often forgets to activate the function or he doesn't consider the amount of food large enough to manually activate the function. As a consequence in these cases, the cooling process is relatively slow.
A refrigerator having the features listed in the appended claims solves the above problem.
The present invention provides a control algorithm able to estimate the amount of warm food inserted into the refrigerator or freezer. On the basis of this estimation, the algorithm automatically tunes the compressor response in order to speed-up the cooling process without wasting any energy for unnecessary over-cooling.
In this way the user is not required to activate manually the fast cooling function, and any waste of energy, due to over-cooling, is avoided.
The above mentioned and other features and objects of the present invention, and the manner of attaining them, will become more apparent and the invention

itself will be better understood by reference to the following description taken in conjunction with the accompanying drawings in which:

- Figure 1 shows a typical temperature trend inside a freezer when the user puts a quantity of warm food inside the cavity without any "Fast-Freezing" function,
- Figures 2a and 2b show a comparison between a warm food recovery without any "Fast Freezing" function (prior art) and a warm food recovery according to the present invention respectively, highlighting how the present invention allows a higher speed in the warm food recovery,
- Figure 3 shows the behavior of the control including the proposed invention in response to three different insertions of warm food quantities,
- Figures 4a and 4b show a comparison between a warm food recovery with the known "Fast-Freezing" function activated and a recovery according to the present invention respectively, highlighting how the traditional fast freezing function can cause an excessive and unnecessary food "under-cooling",
- Figure 5 shows a comparison between energy consumption vs. time obtained with the known fast freezing function (in the working condition shown in fig. 4a) and the energy consumption obtained with a refrigerator according to the present invention (in the working condition of fig. 4b),
- Figures 6 and 7 show the main parameters of the probe temperature trend that can be used in the estimation of the amount of food and, by consequent, in controlling the compressor cooling capacity.

With reference to the drawings, in which experimental data were obtained with a Whirlpool side by side refrigerator model *s25brww20-a/g*, figure 1 shows a typical and well-known temperature trend inside a freezer when the user puts a quantity of warm food inside the cavity. In the first instants the probe temperature rapidly increases its detected value. When the user closes the door, the temperature starts going down thanks to the traditional temperature control action, based on a consequent increase of the cooling capacity of the compressor (in the example the speed of the variable speed compressor increases from 1500 rpm to 4000 rpm). The higher is the amount of warm food inside the freezer, the slower the

probe temperature tends to go down. According to the gist of the present invention, the refrigerator control system, receiving inputs from the probe temperature inside the freezer and possibly inputs related to the working condition of the compressor, can estimate the amount of warm food (warm thermal mass) by correlating the behavior (for instance the slope) of the probe temperature with the actual compressor capacity. The food cooling speed is then increased by increasing the compressor capacity proportionally to the estimated warm thermal mass and substantially independently on the actual temperature reached by the probe after such compressor capacity has been increased.

Figures 2a and 2b show two ways of warm food recoveries: the first one (fig. 2.a) is the result obtained by a traditional control (no warm food estimation and no fast freezing activated by the user), the second one is obtained by a control that implements the method according to the invention. It can be noticed how the known control doesn't perform any probe "under-cooling": as the temperature probe reaches the cut-off temperature, the compressor is shut down but the food is not yet completely cooled. On the contrary, the proposed algorithm performs an appropriate probe "under-cooling" by running the compressor at high speed and for a time depending on the previous estimation of the amount of food loaded into the freezer. Also the speed at which the compressor runs may be set by the control system on the basis of the above estimation. As a further result of the method according to the invention, the compressor may be shut down when the package is completely cooled. The probe "under-cooling", in which the usual control based on cut-off temperature is "overruled", is represented by the area named A2 in the figure 2b. After the package loaded into the freezer is sufficiently cooled, the usual method of controlling the compressor, in which the compressor is switched off when the cut off temperature is reached, is resumed.

Referring to figure 6, a possible technique for estimating the amount of warm food and to carry out an appropriated probe "under-cooling" is based on the estimation of the A1 area, i.e. the integral of the curve representing the increase of temperature above a steady state average temperature Tg. If A1 is the probe temperature area caused by the warm package insertion, the control algorithm

drives the compressor to an appropriate speed in order to guarantee an "under-cooling" area A2 that is proportional to the area A1, i.e. $A2=k \cdot A1$. The parameter k may depend on the type of appliance. Furthermore, on the same appliance, this parameter may be constant or changed with the working conditions (i.e. external temperature, temperature set by the user etc), and fuzzy logic may be used for this purpose.

An alternative technique consists in having an area A2 based on time derivative of the probe temperature, i.e. with A2 in inverse proportion to such derivative: the lower is the derivative, the higher must be A2.

Additional information to decide the "under-cooling" area A2 can be obtained considering the probe temperature value T_x when the user closes the door (after the insertion of the food) and by analyzing the consequent interval time Dt_x, the temperature difference DT_x and the area A_x as shown in figure 7. In general, the higher is the amount of warm food, the higher these 3 parameters are. Nevertheless other parameters (in addition to the amount of warm food) may affect these parameters (DT_x Dt_x and A_x) and one of these is the external temperature. For this reason, if an external temperature sensor is available in addition to the usual internal temperature sensor, the measure of the above three parameters can be correlated with the measure of external temperature sensor to improve the warm food temperature estimation.

The same techniques described in the previous paragraphs can be used also to decide an appropriated interval time Dt in which the compressor must be forced to run at an appropriated level of power (for instance at the maximum one).

Of course any combination of the previous techniques can be used.

A possible practical implementation of these control techniques can be carried out by a temperature control algorithm based on the PID (Proportional-derivative-integral) technique.

With such a kind of algorithm, the compressor cooling capacity u(t) (in general the compressor speed) will depend on the error temperature e(t) according to the following formula:

$$u(t) = Kp * [e(t) + \frac{1}{Ti} * \int_0^t e(\tau)d\tau + Td * \frac{de(t)}{dt}]$$

Where the temperature error *e(t)* is defined as: *e(t)= Tprobe-Target,* Ti is the integral time, Td is the derivative time and Kp is a predetermined parameter.

The integral component plays the main role in adapting the cooling capacity to the amount of warm food. In fact it is proportional to the area of the error *e(t)* along the time axes. During a recovery, this area is significantly affected by the amount of warm food: the higher is the amount of warm food, the longer *e(t)* tends to be "high" (>0) with a consequent increasing of its area (see area A1 in fig 2a ,2b). This condition leads to a progressive increasing of the compressor capacity u(t). Furthermore, the integrative component guarantees an appropriate probe "under-cooling" to compensate the positive area caused by the insertion of the warm food.

The integral time Ti, the derivative time Td and the predetermined parameter Kp are adjusted according to data related to opening door switch (i.e. according to frequency and/or time of door aperture) or, if such data are not available, from a sudden rising temperature detection to speed up the food cooling time. Such adjustment can act together or replacing the well known "anti wind-up" technique in which the integrative part of the temperature error may or not be saturated to a predetermined value.

Figure 3 shows the capability of the control algorithm to adapt the compressor response to the warm thermal mass. In particular it is shown the reaction to the insertion of high, medium and small food quantities . In each of these three conditions the control gives a compressor capacity increase that is proportional to the warm thermal mass. As a consequence of the increased cooling capacity, the temperature probe is proportionally "under-cooled" as well. In particular figure 3 highlights the different probe under-cooling for each warm food quantity (see the different "under-cooling" areas A_1, A_2, A_3). For this reason, one of the main characteristics of the control algorithm according to the present invention consists

in the fact that the compressor switch-off is not based on a predetermined cut-off temperature (or a set of predetermined cut-off temperatures): the compressor is switched off on the basis of the estimated amount of warm food that the user has put inside the freezer cavity. In the example shown in fig. 3, the compressor was switched off at different temperatures T_{off1}, T_{off2}, T_{off3}.

The main advantages of the present invention are as follows. The algorithm adapts the compressor response to the warm thermal mass avoiding any waste of energy for unnecessary over-cooling. In particular, fig. 4a shows the effects of the traditional fast freezing function manually activated by the user: in this case a medium load quantity of warm food has been inserted into the freezer. The traditional fast freezing function keeps the compressor running at its maximum capacity for 24 hours with a consequent under cooling of the food with a consequent waste of energy. Figure 4b shows the automatic fast freezing performed by the method according to the present invention in the same working condition of figure 4b: without any user interaction the same amount of warm food is rapidly recovered without unnecessary food "under-cooling". Figure 5 shows the comparison between the energy consumption in the two above cases.

The method according to the invention is completely automatic, this means that the user is not required to activate any function. So the risk of a slow temperature recovery, when the user forgets to activate the fast freezing function present in known refrigerators, is avoided.

CLAIMS

1. A refrigerator comprising a compressor having a variable cooling capacity and control means for controlling such compressor in response to the temperature inside the refrigerator, characterized in that the control means are adapted to detect the variation of temperature inside the refrigerator due to the loading of a food item, and to adjust the cooling capacity of the compressor accordingly.
2. A refrigerator according to claim 1, characterized in that the control means are adapted to increase the cooling capacity of the compressor proportionally to the estimated thermal mass of the food item.
3. A refrigerator according to claim 1 or 2, characterized in that the compressor is a variable speed compressor
4. Method for controlling the variable cooling capacity of a compressor in a refrigerator having a variable cooling capacity compressor, in which such control is based on temperature signal from a temperature sensor inside the refrigerator, characterized in that the variation of temperature due to the loading of a food item is detected and the cooling capacity of the compressor is adjusted accordingly in order to have a quicker cooling of such food item.
5. Method according to claim 4, characterized in that it comprises the following step:
- detecting any variation of temperature above a predetermined average temperature value due to the loading of a food item inside the refrigerator,
- estimating the integral of said temperature variation vs. time,
- increasing the cooling capacity of the compressor so that the integral of the variation of temperature below said predetermined average temperature, due to the increased cooling capacity of the compressor, is proportional to the integral of the variation of temperature above said predetermined value.
6. Method according to claim 4, characterized in that it comprises the following steps:

- detecting any variation of temperature above an average predetermined value due to the loading of a food item inside the refrigerator,
- estimating the derivative of temperature vs. time in the decrease of temperature due to the intervention of the control,
- increasing the cooling capacity of the compressor so that the integral of the variation of temperature below said average predetermined temperature value, due to the increased cooling capacity of the compressor, is in inverse proportion to the integral of the variation of temperature above said predetermined value.

7. Method according to claim 4, characterized in that the cooling capacity u(t) of the compressor is adjusted with a control algorithm based on a PID technique according to the following formula:

$$u(t) = Kp * [e(t) + \frac{1}{Ti} * \int_0^t e(\tau)d\tau + Td * \frac{de(t)}{dt}]$$

where the temperature error *e(t)* is defined as: *e(t)= Tprobe-Target,* Ti is the integral time, Td is the derivative time and Kp is a predetermined parameter.

8. Method according to claim 7, characterized in that the integral time Ti, the derivative time Td and the predetermined parameter Kp are adjusted according to the opening door switch or, if not available, from a sudden rising temperature detection.

9. Method according to claim 7, characterized in that the cooling capacity of the compressor is adjusted by changing its speed u(t).

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Title: A refrigerator with a variable speed compressor and a method for controlling variable cooling capacity thereof

Abstract

A refrigerator comprises a variable speed compressor and control means for controlling such compressor in response to the temperature inside the refrigerator. The control means are adapted to detect the variation of temperature inside the refrigerator due to the loading of a warm food item, and to adjust the speed of the compressor accordingly.

(figure 2)

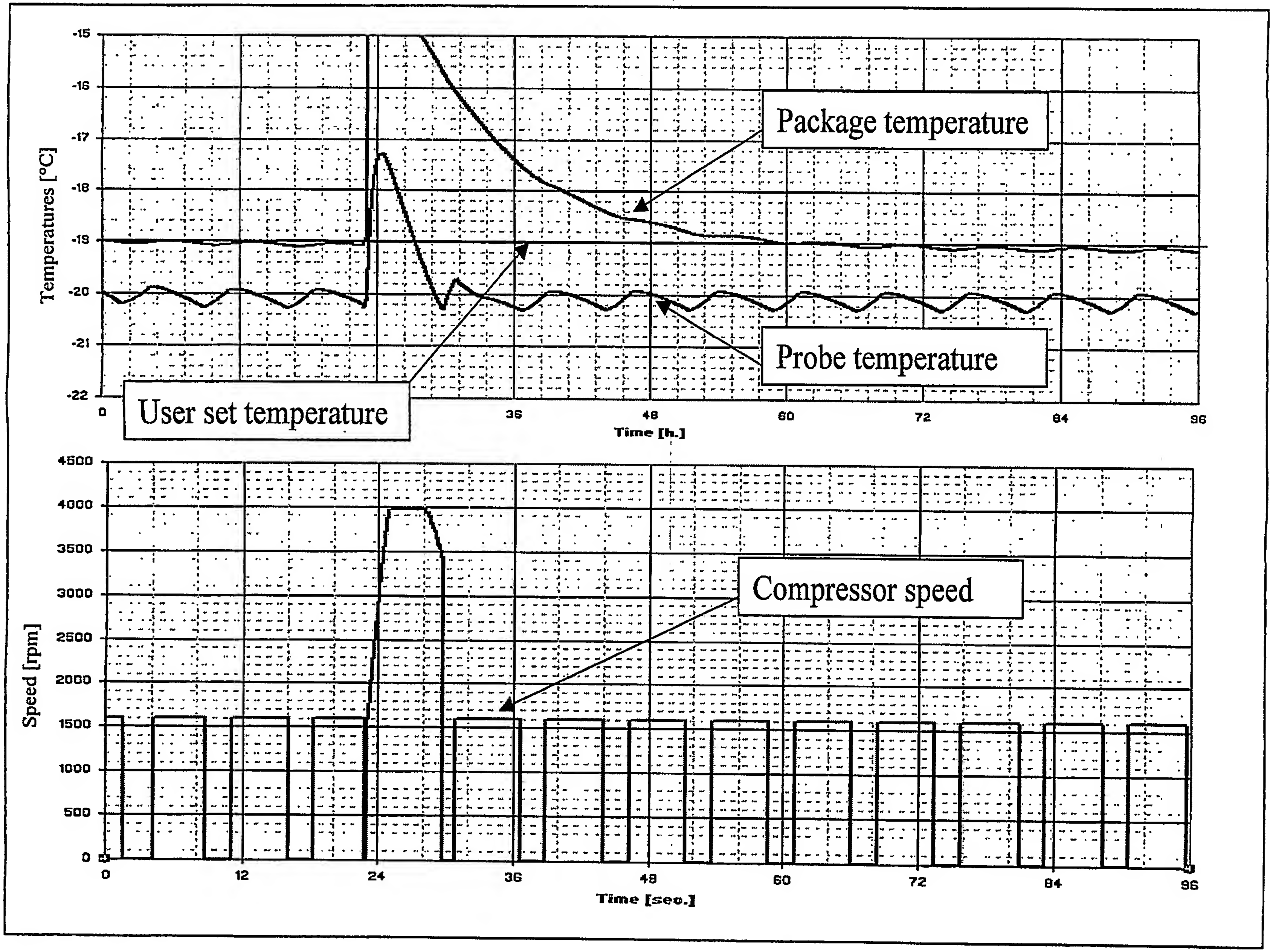
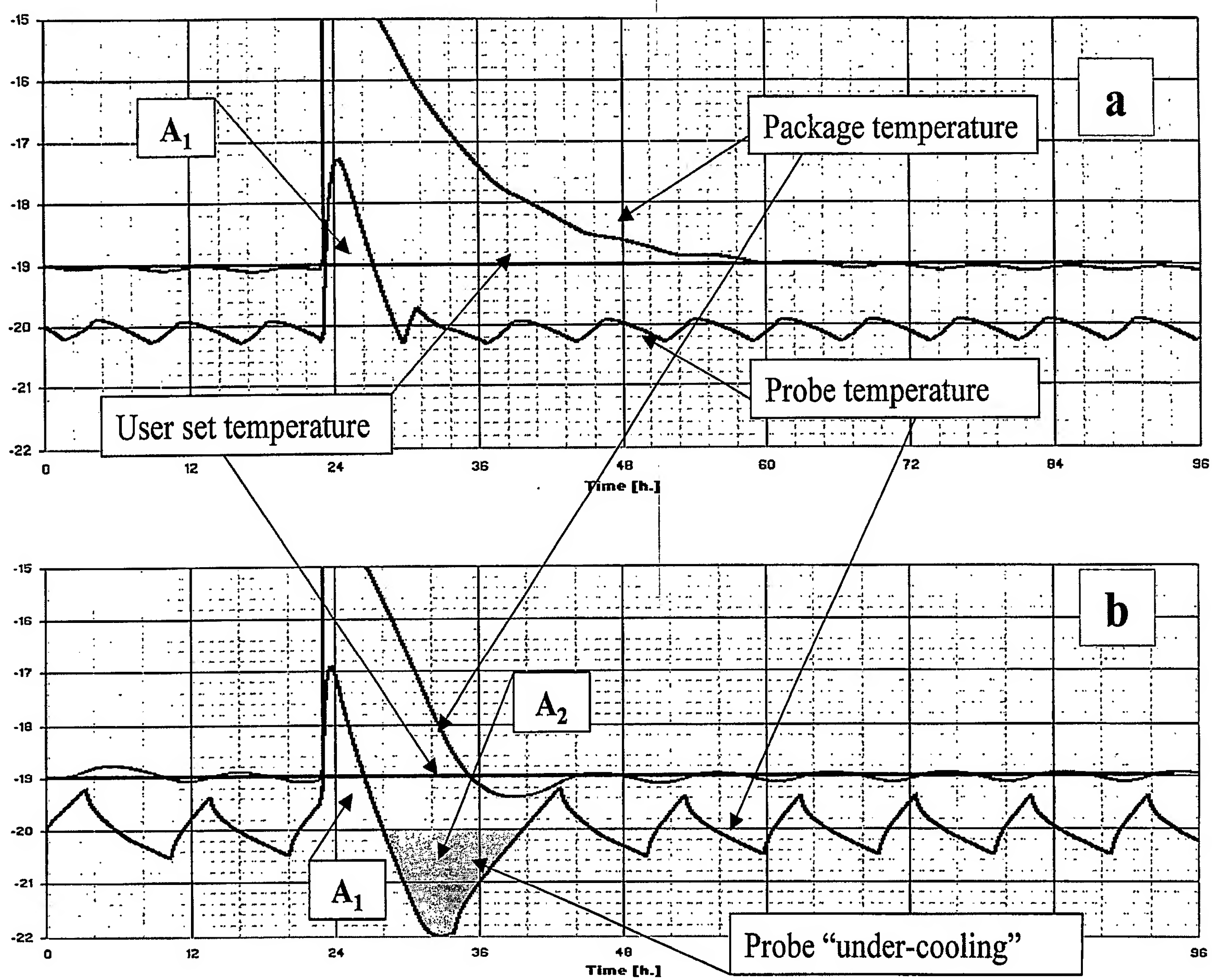

Package temperature
Probe temperature
User set temperature
Temperatures [°C]
-15
-16
-17
-18
-19
-20
-21
-22
0
36
48
60
72
84
96
Time [h.]
Compressor speed
Speed [rpm]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
12
24
36
48
60
72
84
96
Time [sec.]

Figure 1



a
b
A1
A2
Package temperature
Probe temperature
User set temperature
Probe “under-cooling”
Time [h.]

Figure 2

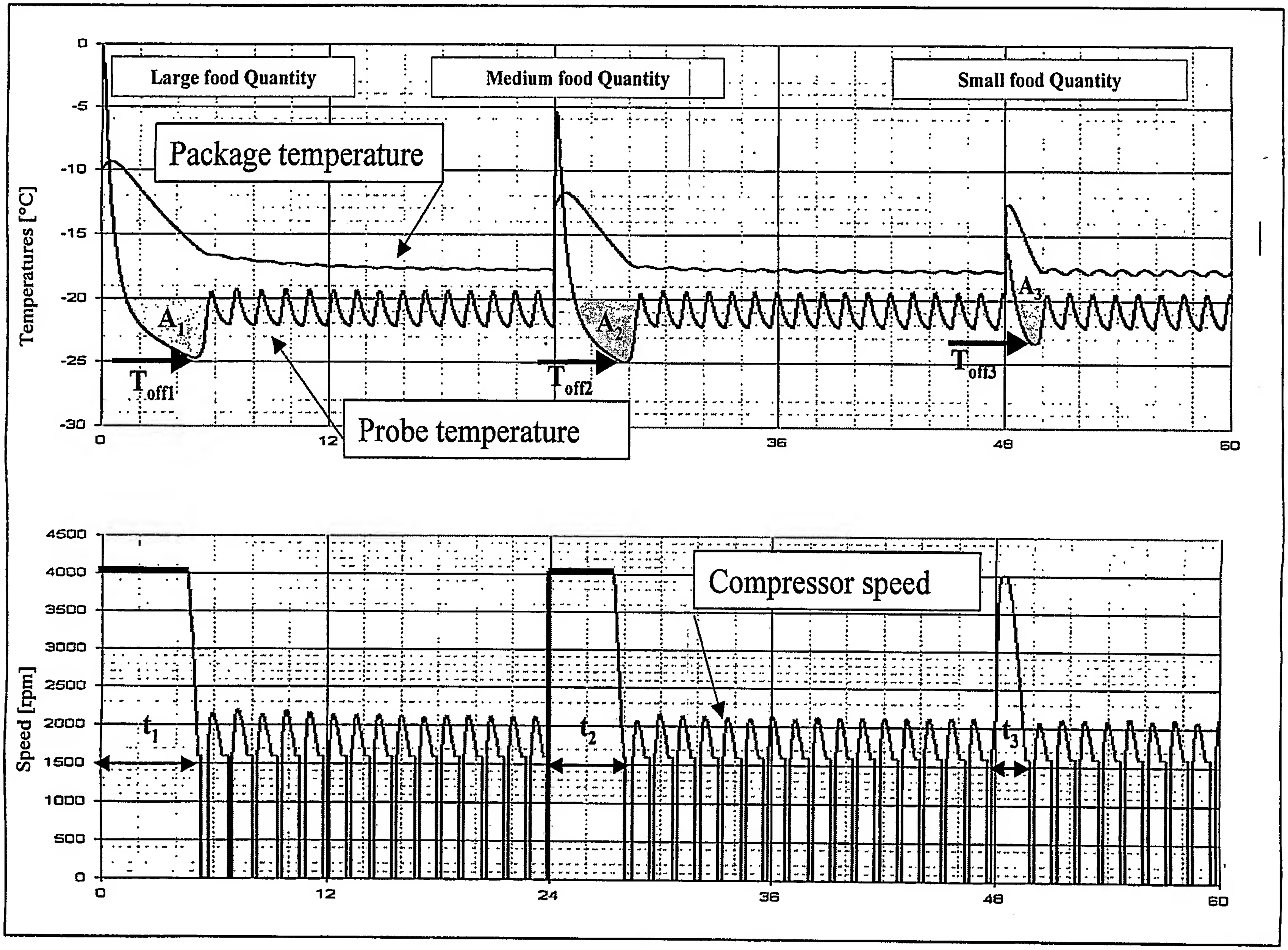

Large food Quantity
Medium food Quantity
Small food Quantity
Package temperature
Probe temperature
Temperatures [°C]
A_1
A_2
A_3
T_{off1}
T_{off2}
T_{off3}
0
-5
-10
-15
-20
-25
-30
0
12
36
48
60
Compressor speed
Speed [rpm]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
t_1
t_2
t_3
0
12
24
36
48
60

Figure 3

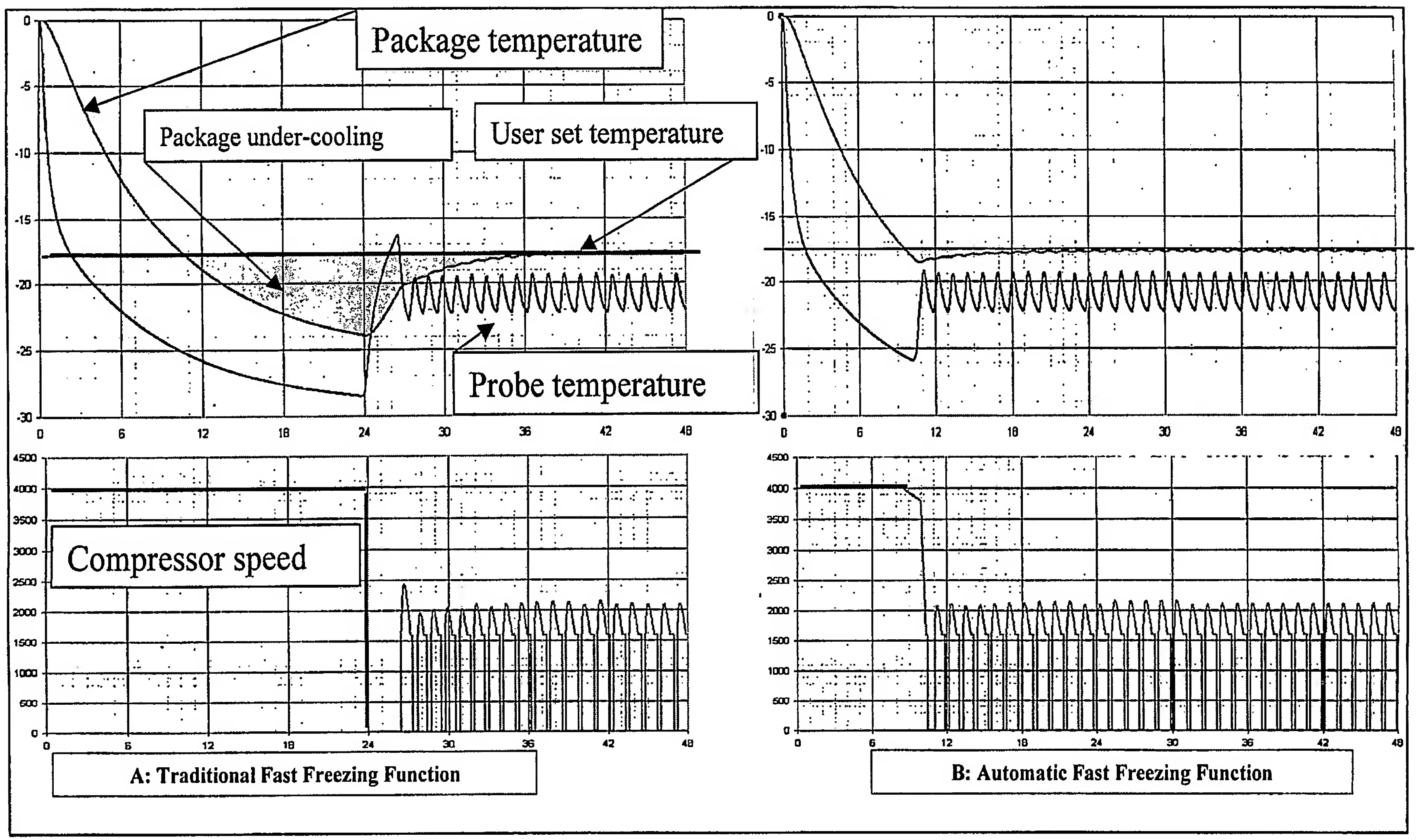

Package temperature
Package under-cooling
User set temperature
Probe temperature
Compressor speed
A: Traditional Fast Freezing Function
B: Automatic Fast Freezing Function

Figure 4

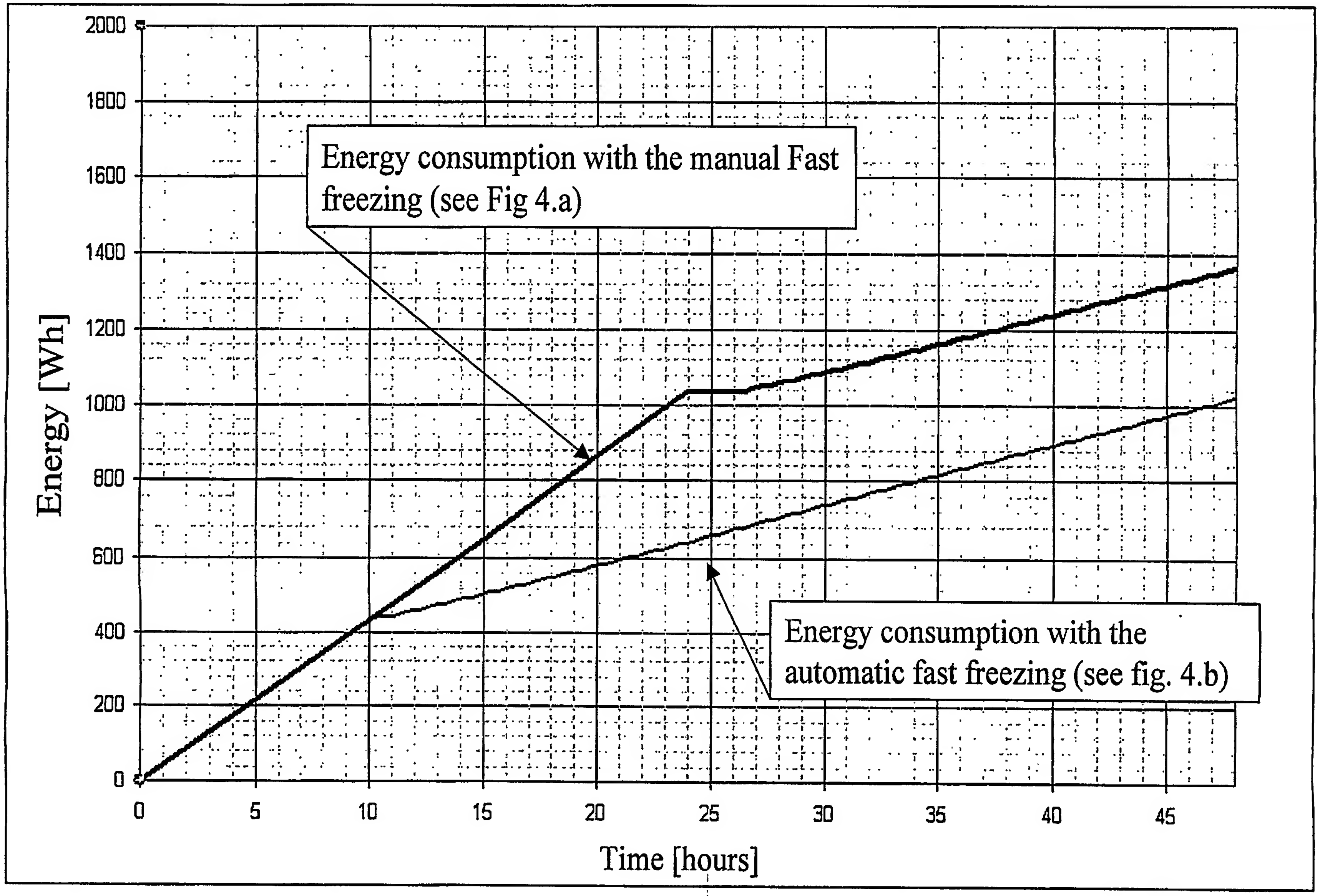
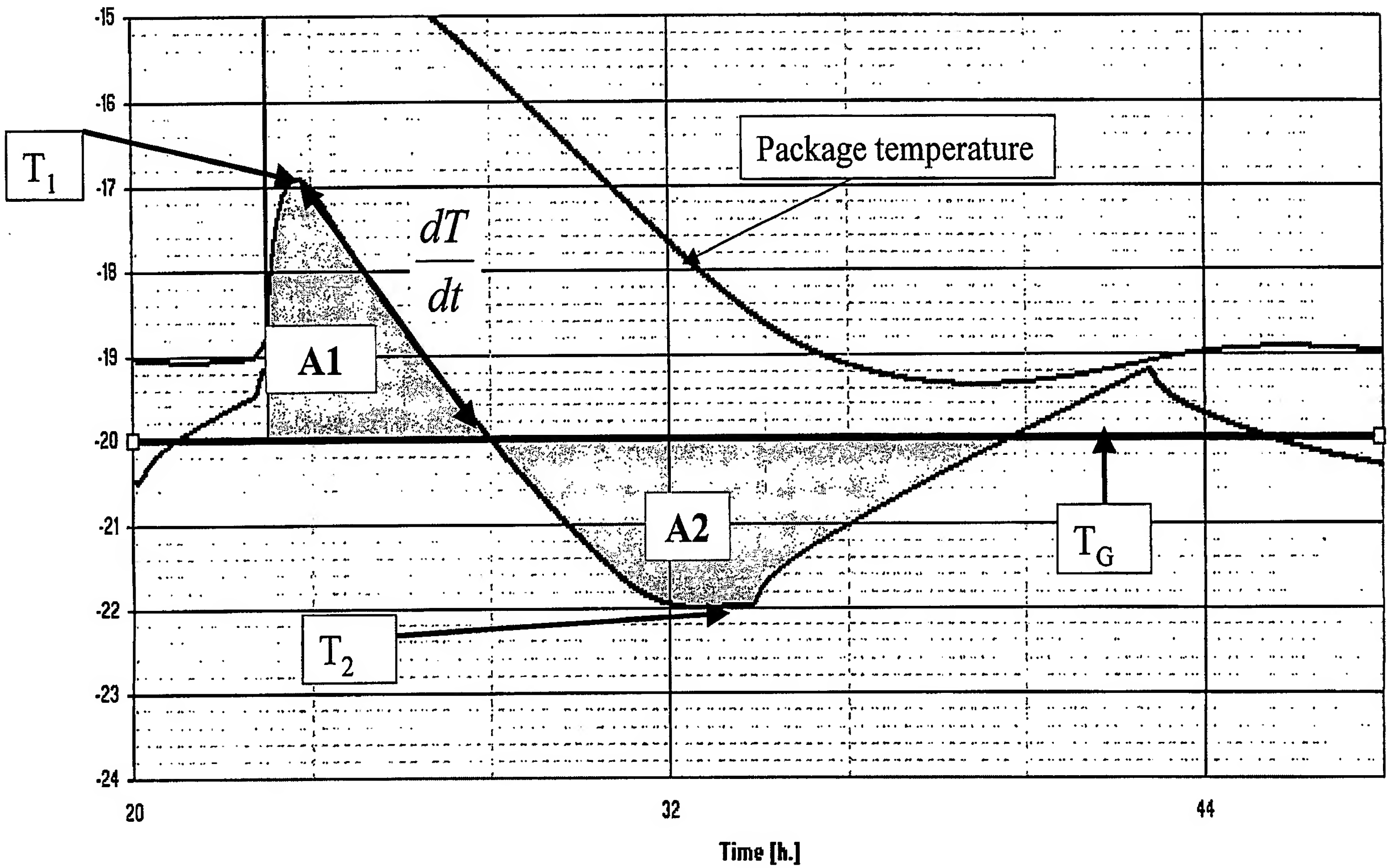

Energy [Wh]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
Time [hours]
Energy consumption with the manual Fast freezing (see Fig 4.a)
Energy consumption with the automatic fast freezing (see fig. 4.b)

Figure 5



-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
20
32
44
Time [h.]
T1
T2
TG
A1
A2
dT/dt
Package temperature

Figure 6

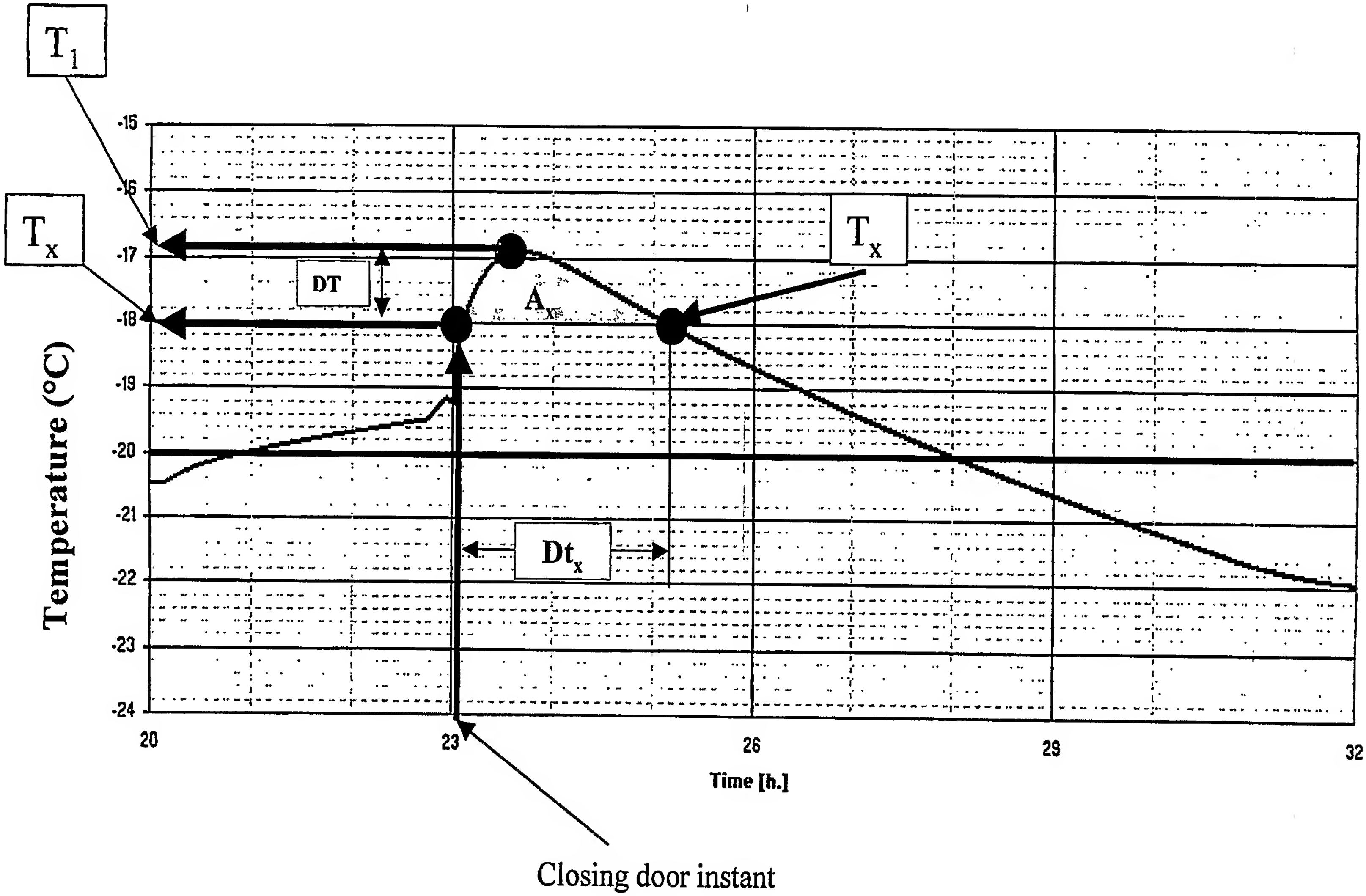

T_1
T_x
T_x
DT
A_x
Dt_x
-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
Temperature (°C)
20
23
26
29
32
Time [h.]
Closing door instant

Figure 7